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TRIAL AND ERROR VS. "INSIGHTFUL" PROBLEM SOLVING--EFFECTS OF DISTRACTION, ADDITIONAL RESPONSE ALTERNATIVES, AND LONGER RESPONSE CHAINS.

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TWO SWITCH-LIGHT PROBLEMS WERE USED TO INVESTIGATE THREE VARIABLES THAT INFLUENCE PROBLEM-SOLVING PERFORMANCE--(1) THE NUMBER OF DISTRACTING RESPONSE ALTERNATIVES, (2) THE NUMBER OF AVAILABLE RESPONSE ALTERNATIVES, AND (3) THE NUMBER OF MINIMALLY REQUIRED RESPONSES. IN THE PROBLEMS USED, THE SUBJECT ATTEMPTED TO ACHIEVE A PARTICULAR PATTERN OF LIGHTS IN A MATRIX BY MANIPULATING SWITCHES ON HIS RESPONSE PANEL. IN BOTH EXPERIMENTS THE SUBJECTS WERE DIVIDED INTO TWO GROUPS. SUBJECTS IN GROUP O SOLVED THE PROBLEMS LARGELY BY OVERT TRIAL-AND-ERROR BEHAVIOR. SUBJECTS IN GROUP C WERE TAUGHT WHICH LIGHTS WERE CONTROLLED BY EACH SWITCH AND SOLVED THEIR PROBLEMS MAINLY BY IMPLICIT OR "INSIGHTFUL" BEHAVIOR. EXPERIMENT I USED 48 COLLEGE STUDENTS TO COMPARE THE EFFECTS OF BOTH THE NUMBER OF DISTRACTING SWITCHES AND THE TOTAL NUMBER OF AVAILABLE SWITCHES UPON PERFORMANCE IN THE TRIAL-AND-ERROR VERSUS THE INSIGHTFUL FORMS OF THE SWITCH-LIGHT TASK. EXPERIMENT II USED 32 STUDENTS TO EVALUATE THE EFFECTS OF THE NUMBER OF MINIMALLY REQUIRED SWITCHES UPON PERFORMANCE IN THE OVERT TRIAL-AND-ERROR VERSUS INSIGHTFUL FORMS OF THE PROBLEM-SOLVING TASK. PERFORMANCE BY BOTH GROUPS DETERIORATED WHEN (1) A DISTRACTING SWITCH WAS PRESENT, (2) THE NUMBER OF AVAILABLE SWITCHES WAS INCREASED, AND (3) THE NUMBER OF SWITCHES REQUIRED FOR A SOLUTION WAS INCREASED. THE AUTHOR DISCUSSED SOME GENERALIZATIONS FROM THE RESULTS THAT MAY HAVE IMPLICATIONS FOR CLASSROOM INSTRUCTION. (AL)

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WISCONSIN RESEARCH AND DEVELOPMENT
CENTER FOR
COGNITIVE LEARNING

Technical Report No. 26

TRIAL AND ERROR VS. "INSIGHTFUL" PROBLEM SOLVING: EFFECTS OF DISTRACTION, ADDITIONAL RESPONSE ALTERNATIVES, AND LONGER RESPONSE CHAINS

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PREFACE

The goal of the Wisconsin R & D Center for Cognitive Learning is to contribute to an understanding of, and the improvement of educational practices related to, cognitive learning by children and youth. Of primary concern are the learning of concepts and the nurturing of related cognitive skills. Conditions within the learner and conditions within the learning situation are also relevant areas of research and development.

This Technical Report is an extension of Professor Davis' earlier investigations of important pretraining variables which influence performance in human problem solving (Davis 1965, 1966, 1967). The task is a switch-light problem in which the S attempts to achieve a particular pattern of lights in a matrix by manipulating switches on his response panel. The variables investigated—number of distracting response alternatives, number of available response alternatives, and number of minimally required responses—were shown to influence performance on either an overt trial-and-error form of the task or an implicit "insightful" form of the task. Such a problem-solving situation is, of course, a highly structured laboratory task. Yet Professor Davis feels the particular variables manipulated are common to many classroom problem situations and therefore merit careful analysis.

Herbert J. Klausmeier
Co-Director for Research

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ABSTRACT

Three variables were manipulated in a problem-solving task which required S to achieve a particular pattern of lights in a matrix by locating relevant switches on his response panel. Ss in Group O solved their problems largely by overt trial-and-error problem-solving behavior; Ss in Group C, who had been taught which lights were controlled by each switch, solved their problems mainly by implicit or "insightful" problem-solving behavior. Performance by both groups deteriorated (1) when a distracting switch (response) was present, (2) with increases in the number of available switches, and (3) with increases in the number of switches required for solution. Some implications for education were suggested.

I
INTRODUCTION

One important goal of the Wisconsin Research and Development Center for Cognitive Learning is the clarification of human problem-solving behavior. An important aspect of problem solving is the identification and analysis of pretraining and task variables which critically influence problem-solving performance. The experiments reported here constitute an extension of the first author's earlier work (Davis, 1965, 1967) in which some important pretraining and task variables were manipulated using a switch-light problem-solving task as a laboratory analogue of real-world human problem-solving behavior.

In a switch-light problem-solving task, S is required to achieve a particular pattern of lights in a matrix by locating relevant switches on his response panel (Davis, 1965, 1966, 1967; Duncan, 1963; John, 1957; Pylyshyn, 1963). In the earlier experiments (Davis, 1967, Experiments I & II), it was found that performance in the switch-light task was drastically impaired by (1) increases in the number of distracting switches (reinforced but incorrect response alternatives), (2) increases in the number of available switches (size of the response pool), and (3) increases in the number of switches minimally required for solution (interpreted as the length of the problem-solving response chain). In a final experiment (Experiment III), it was shown that this type of task, usually approached by overt trial-and-error problem-solving behavior, was solvable by errorless "insightful" behavior, if Ss were appropriately pretrained. This pretraining consisted of teaching Ss exactly which lights were controlled by each switch prior to solving their problems.

The purpose of the present experiments was to determine if the variables shown to influence performance in the overt trial-and-error form of the task would also influence performance in the "insightful" (pretrained, implicit trial-and-error) form of the same problem-solving situation. Since the overt trial-and-error form of problem solving was conceived as being somewhat similar in kind to the implicit trial-and-error form of problem solving, the prediction for the present experiments was that the variables manipulated would have similar effects upon performance in each of the two forms of the problem-solving task.

II
EXPERIMENT I

The goal of Experiment I was to compare the effects of both the number of distracting switches (response alternatives) and the total number of available switches upon performance in the trial-and-error vs. the insightful forms of the switch-light task.

METHOD

Subjects

The Ss were 48 students taking elementary learning courses in educational psychology at the University of Wisconsin.

Apparatus

The stimulus display unit consisted of a 4 x 4 matrix of 1-in. lights placed 4 in. apart (on center) upon a black relay-rack panel. The rack panel itself was mounted vertically at about S's seated eye level on a standard open-type relay rack. The four lights in the bottom row were amber and were used only for demonstration and practice manipulations, thus reducing the functional stimulus array to a 3 x 4 matrix of lights, with three rows and four columns. All lights in the 3 x 4 problem matrix were white except for two red lights.

The S's response panel consisted of a 4 x 4 matrix of spring-return lever switches mounted on a standard chassis. The unit, fixed to the relay rack just below and in front of the stimulus display, sloped toward S. When pressed, each switch would change the state of two lights from off to on, or on to off. The two lights operated by any one switch were always directly adjacent, horizontally or vertically, to each other in the light matrix. To clearly indicate to S the available pool of lever switches, the small black plastic handles were removed from all switches not used in a given problem. The switches and lights were not numbered, lettered, or otherwise marked.

Pretraining

All Ss were instructed concerning the operation of the switches and lights, and all were given some simple manipulations intended to further familiarize them with the apparatus (See Davis, 1967). At this point, half of the Ss were taught which two lights were controlled by each switch. These Ss will be referred to as Group C (covert) Ss. Essentially an anticipatory-type paired-associates procedure was used in which Ss were asked to anticipate, by pointing, which two lights would be turned on by each switch in the "list" of switches. A fairly rigid criterion of four errorless trials, not necessarily consecutively, was used to insure overlearning. All lights were white for the pretraining task.

The Problem

The nature of his problem was explained to each S in Group C directly following reaching criterion on the pretraining task. The Ss in Group O (overt), who did not receive this pretraining, received the explanation directly following the general instructions and familiarization procedures.

Specifically, Ss task was to manipulate the switches until only the two red lights, in the matrix of white lights, remained on. He was instructed to minimize switch presses and to take whatever time he needed.

In a problem requiring three switches to solve, the two red lights were positioned in the light matrix analogously to the move of a chess knight, e.g., if one red light were placed in the upper left corner of the matrix, the other might be located two columns to the right and one row down. Figure 1 contains an example of a problem. The problem was solved by locating a switch which turned on one red light plus a white light which lies between the red lights (e.g., Switch 6 in Fig. 1); a second switch turned on the other red light plus another intervening white light (Switch 10); and

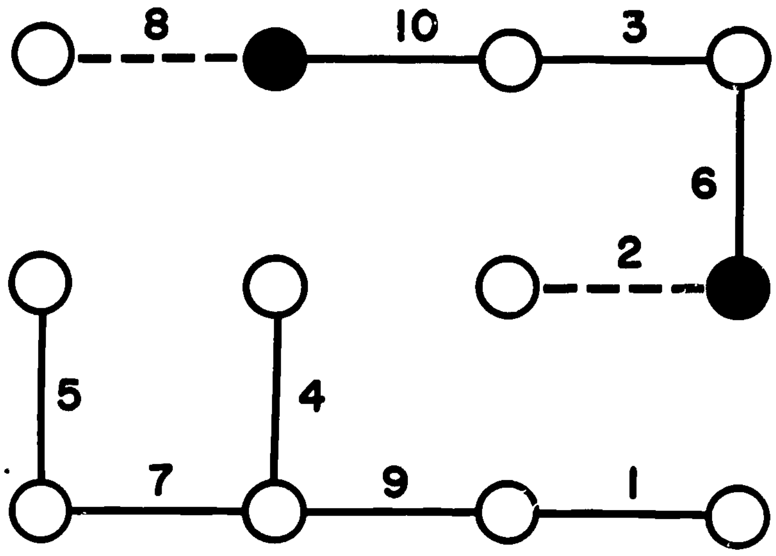

Fig. 1. Example of a problem involving 10 switches. (Three switches are relevant—No. 3, 6, and 10—two are distracting—2 and 8—and five switches are irrelevant—1, 4, 5, 7, and 9.)

a third switch turned off the two white lights (Switch 3), leaving only the two red lights on. In practice, the three relevant switches could be pressed in any order. All other switches turned on lights which eventually had to be turned off in order to solve the problem. The S repeatedly solved the same problem until he chose the three necessary switches without error.

The notion of distracting or misleading switches (or responses) is central to the present experiments. Operationally, a switch is a distractor if one member of the two lights operated by that switch is a crucial red light, yet the switch cannot be used for problem solution. It is important to note that, as demonstrated elsewhere (Davis, 1965), a change in the state of the red lights is reinforcing and responses to switches controlling the red lights are strengthened. Thus responses to both relevant (correct) and distracting (incorrect) switches are strengthened, but the problem will remain unsolved until responses to the distracting switches are extinguished. In Fig. 1, dashed lines indicate the light pairs operated by distractor switches, Switches 2 and 8 in this example. In the course of a problem, these two switches turn on the red lights, but the problem remains unsolved until S presses the distractor switches again, hence negating a previous incorrect response.

Design

A 2 x 2 x 3 factorial design included two levels of pretraining (Group C vs. Group O, as described above), two levels of "distraction" (0 or 1 distracting switch), and three variations in the number of available switches (6, 9, or 12 switches used in a problem). Since each S solved one problem, there were four Ss in each of the 12 treatment combinations.

Dependent measures included (1) switch presses (or total responses) to criterion, (2) total time to solution, (3) number of repetitions of the same problem (trials), and (4) a derived measure of mean response latency (sec. per response).

RESULTS AND DISCUSSION

Effectiveness of Pretraining

Of the 24 pretrained Ss in Group C, 10 Ss demonstrated errorless long-latency problem solving. The remaining 14 Ss required very few overt switch presses and very few trials (repetitions of the same problem) to reach criterion. Over all Ss in Group C, the mean response latency was 13.9 sec. per switch press and Ss required 12.6 switch presses and 2.12 trials to reach criterion. In contrast, the untrained Ss in Group O approached the task by short-latency overt trial-and-error behavior and required, on the average, 166.1 switch presses and 5.8 trials to reach criterion and used only 2.4 sec. per switch press. The pretraining was considered successful in creating "insightful" vs. trial-and-error approaches to the same problem-solving task.

Total Switch Presses and Total Time

The effects of number of distracting switches (responses) and number of available switches upon total switch presses and total time to criterion are shown in Figure 2. An analysis of variance on the switch-press data showed significant effects of pretraining, $F(1,36) = 68.89$, $p < .001$; number of available switches, $F(2,36) = 7.06$, $p < .01$; and number of distracting switches, $F(1,36) = 17.81$, $p < .001$. The pretraining by number of available switches interaction was significant, $F(2,36) = 7.04$, $p < .01$, as was the pretraining by distractor interaction, $F(1,36) = 16.73$, $p < .001$. Together, these significant interactions reflect the fact that, for the insightful problem solvers of Group C, there were no systematic effects of either the number of distracting switches or the number of available switches upon total switch presses since, as discussed above, overt responding was mostly unnecessary for

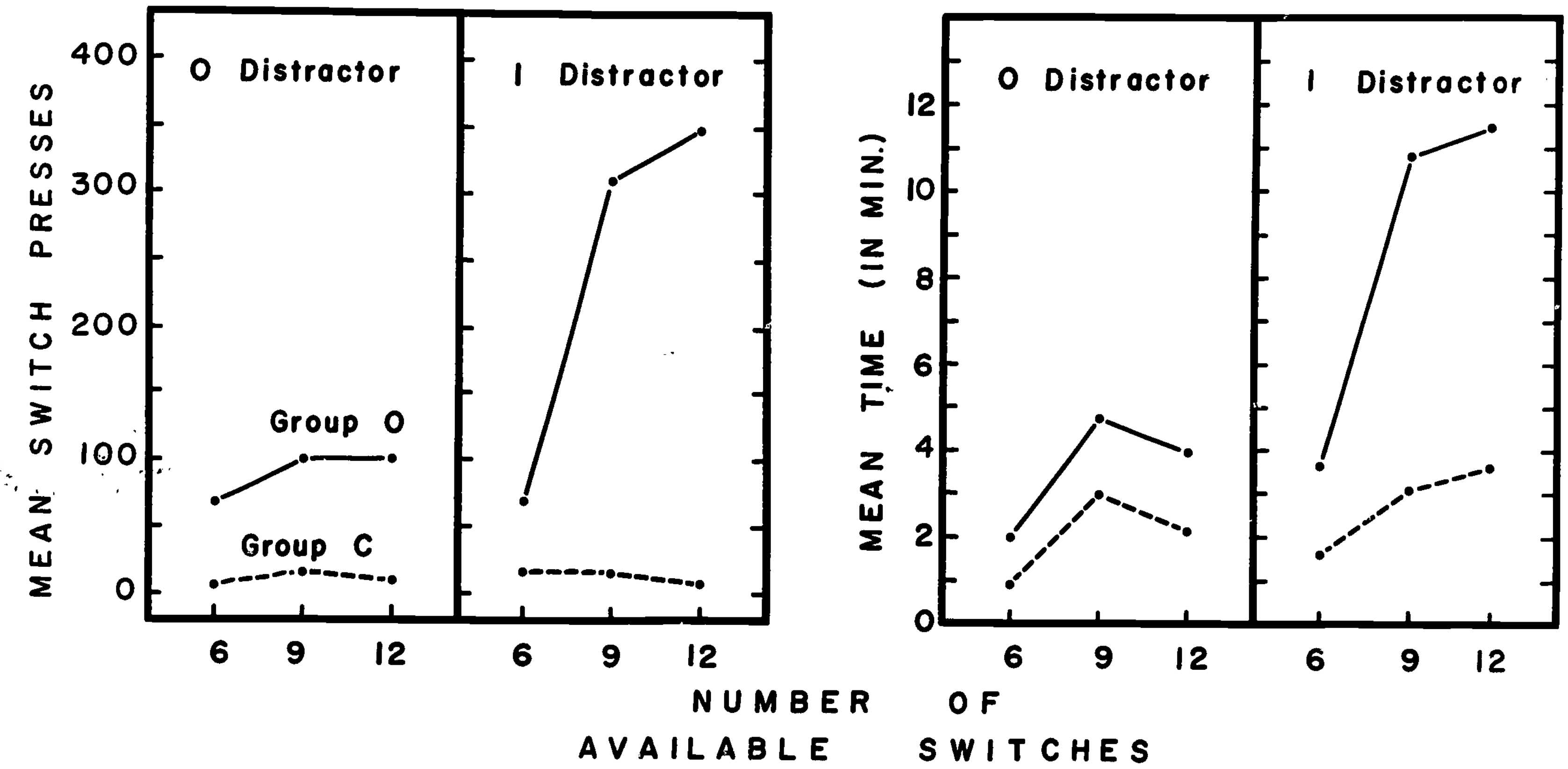

Fig. 2. Mean switch presses and mean time to criterion as a function of number of available switches, number of distracting switches, and pretraining (Group O vs. Group C).

these Ss. Also, the number of available switches by number of distractors interaction reached significance, $F(2, 36) = 3.88$, $p < .05$, and the second-order interaction of pretraining by available switches by distractors interaction was significant, $F(2, 36) = 4.84$, $p < .025$, indicating that, for Group O, additional response alternatives were more detrimental to performance in problems with a distractor present.

The right half of Figure 2 shows that for the overt trial-and-error Ss (Group O), the total time to criterion measure reflected about the same effects of distractors and number of available switches as did the switch press measure. For Ss in Group C, the total time to criterion measure (unlike the switch press measure) did reflect variations in performance as a function of the number of distracting switches and the number of available switches. Group C Ss required more time to solution with more available switches and with a distracting switch present in the problem.

Trials

An analysis of variance on the number of repetitions of the same problem (trials) showed that this dependent measure was significantly influenced only by pretraining and by the number of distracting switches, Fs $(1, 36) = 34.13$, $p < .001$, and 4.91, $p < .05$, respectively. Group C Ss in the 0-distractor condition required 2.0 trials to criterion; Group C Ss in the 1-distractor condition required 2.4 trials; Group O Ss in the 0-distractor condition required 4.7 trials; and Group O Ss in the 1-distractor condition required 7.0 trials. The interaction of pretraining by distractors was not significant, $F(1, 36) = 2.39$.

Increasing the number of available switches did not significantly influence the trials measure for Group O or Group C. This indicates that the difficulty associated with more available switches consisted of increases in switch presses and time per trial for Group O, and in time per trial for Group C.

Mean Response Latencies

For each S, his total problem-solving time was divided by his total number of switch presses, producing a derived measure of mean response latency. An analysis of variance on these data showed only that, as mentioned above, pretrained Ss in Group C responded significantly more slowly than the trial-and-error problem solvers of Group O, $F(1, 36) = 27.85$, $p < .001$. No other main effects or interactions reached significance. The absence of a significant distractor main effect is inconsistent with the earlier study (Davis, 1967, Exp. I) in which, using only overt trial-and-error Ss and a wider range of distractors (0, 1, 2, or 3 distracting switches) the distractor main effect was significant at the .025

level, reflecting slower responding with additional distracting switches.

In sum, Experiment I has shown that (1) the same switch-light problem-solving task can be solved by short-latency overt trial-and-error behavior (Group O) or, if Ss learn the switch-light (S-R) relationships in advance, the problem can be solved by long-latency covert or insightful problem-solving behavior (Group C). (2) Increasing the number of available response alternatives (switches) was detrimental to problem-solving performance by both groups, as reflected in the increased time to criterion scores, although performance by the overt trial-and-error group was disrupted more than the performance of the insightful problem solvers. (3) Similarly, the presence of a distracting response alternative impaired problem solving by both groups, but disrupted the performance of Group O more than Group C. (4) For Group O, increasing the number of available response alternatives (switches) resulted in more responses (switch presses) per trial, but not more trials.

III
EXPERIMENT II

The purpose of Experiment II was to evaluate the effects of the number of minimally required switches upon performance in the overt trial-and-error vs. insightful forms of the problem-solving task. This variable, the number of switches which must be used for problem solution, is interpreted as the length of the problem-solving response chain.

METHOD

Subjects

The Ss were 32 students drawn from the same pool as in Experiment I. All Ss received the same basic instructions given in Experiment I, except for being told they would solve four problems instead of one.

As in Experiment I, the Ss were randomly assigned to one of two major groups, the overt trial-and-error group (Group O) and the "insightful" group (Group C). The Ss in Group C received the same pretraining used for Group C in Experiment I; i.e., they learned exactly which two lights were controlled by each switch prior to solving their problems. To insure that Ss in Group C did not forget the switch-light relationships over their four problems, these Ss were required to demonstrate one correct "pretraining" trial prior to each of the last three problems. The red lights were replaced with white ones for these refresher trials.

Design and Procedure

For any given problem, the number of switches required for solution was determined by the relative positions of the two red lights. When the red lights were placed farther apart in the matrix, progressively more relevant switches had to be used in order to solve the problem.

A 4 x 4 Latin square was replicated four times for Group O and four times for Group C. The Latinized variable was the number of required switches, 2, 3, 4, or 5 switches. Thus each of the 32 Ss solved one problem requiring 2 switches for solution, one problem requiring 3 switches, one problem requiring 4 switches, and one problem requiring 5 switches. The order of presentation of the four problems was determined by a row of the Latin square. Across the four problems for any one S, the switches always controlled the same two lights; i.e., the four problems differed only in the placement of the red lights and, of course, in the number of switches required for solution.

For all problems, a total of 8 switches was available and no problem involved the use of distracting switches, as defined in Experiment I.

Problems requiring a longer chain of responses also required more switch presses and more time just for the criterion runs. Therefore, the total switch press and total time to criterion measures were corrected as follows. For each S for each problem, the total switch press score was reduced by the number of switch presses required to meet criterion (number of required switch presses per trial multiplied by the number of trials taken). For example, if 4 switch presses were minimally required for solution, and S took 6 trials to solve the problem, 24 switch presses would be subtracted from his total switch press score. For each S in Group O, the total time to criterion measure was corrected by multiplying the number of criterion switch presses (24 in the present example) by that S's mean response latency (sec. per switch press) and subtracting this product from his total problem-solving time. For Ss in Group C, exactly this time correction could not be used since a perfect solver, regardless of his very slow responding, would always receive a problem-solving time score of zero. Therefore, the total problem-solving times for Ss in Group C were corrected by using the overall mean response latency of Group O (which was 2.14 sec. per switch press). For example, an S in Group C who took 100 sec. and 10 switch presses to solve a 4-switch problem (in 2 trials) would receive a corrected time score of 100 sec. - (4) (2) (2.14 sec.) = 82.88 sec.

RESULTS AND DISCUSSION

Effectiveness of Pretraining

As in Experiment I, the pretraining was effective in producing implicit problem-solving behavior. Of the 64 problems solved by the 16 Ss in Group C, 41 problems were solved without error. Surprisingly, the number of required switches was not systematically related to the number of perfect solutions. For the 2-, 3-, 4-, and 5-required switch problems, there were 13, 8, 10, and 10 errorless solutions, respectively. Over all Ss in Group C, the mean response latency was 10.2 sec. per switch press; the mean number of switch presses per problem (corrected) was 3.5; and the mean number of trials per problem was 1.6. These figures contrast sharply with the mean response latency of 2.12 sec. per switch press, the mean of 86.4 switch presses per problem, and 5.5 trials per problem for the overt trial-and-error Ss in Group O.

It is interesting to note that, in the course of solving their problems, two Ss in Group O (overt trial-and-error) eventually learned the switch-light relationships well enough to solve one problem each in the long-latency, errorless fashion characteristic of Group C Ss. For one S, it was a 2-switch problem occurring third in his sequence of four problems; for the other it was a 3-switch problem occurring fourth.

Total Switch Presses and Total Time

Corrected total switch presses and corrected total time to criterion are shown in Figure 3. An analysis of variance on the switch press data showed the effects of pretraining to be quite reliable, $F\ (1,24) = 49.02$, $p < .001$. For the number of required switches variable (length of problem-solving response chain), $F\ (3,84) = 8.03$, $p < .001$, for the main effect and $F\ (1,84) = 22.27$, $p < .001$, for the linear component. As suggested by the diverging curves in Figure 3, the interaction of pretraining and number of required switches was significant, $F\ (3,84) = 6.74$, $p < .001$. Also,

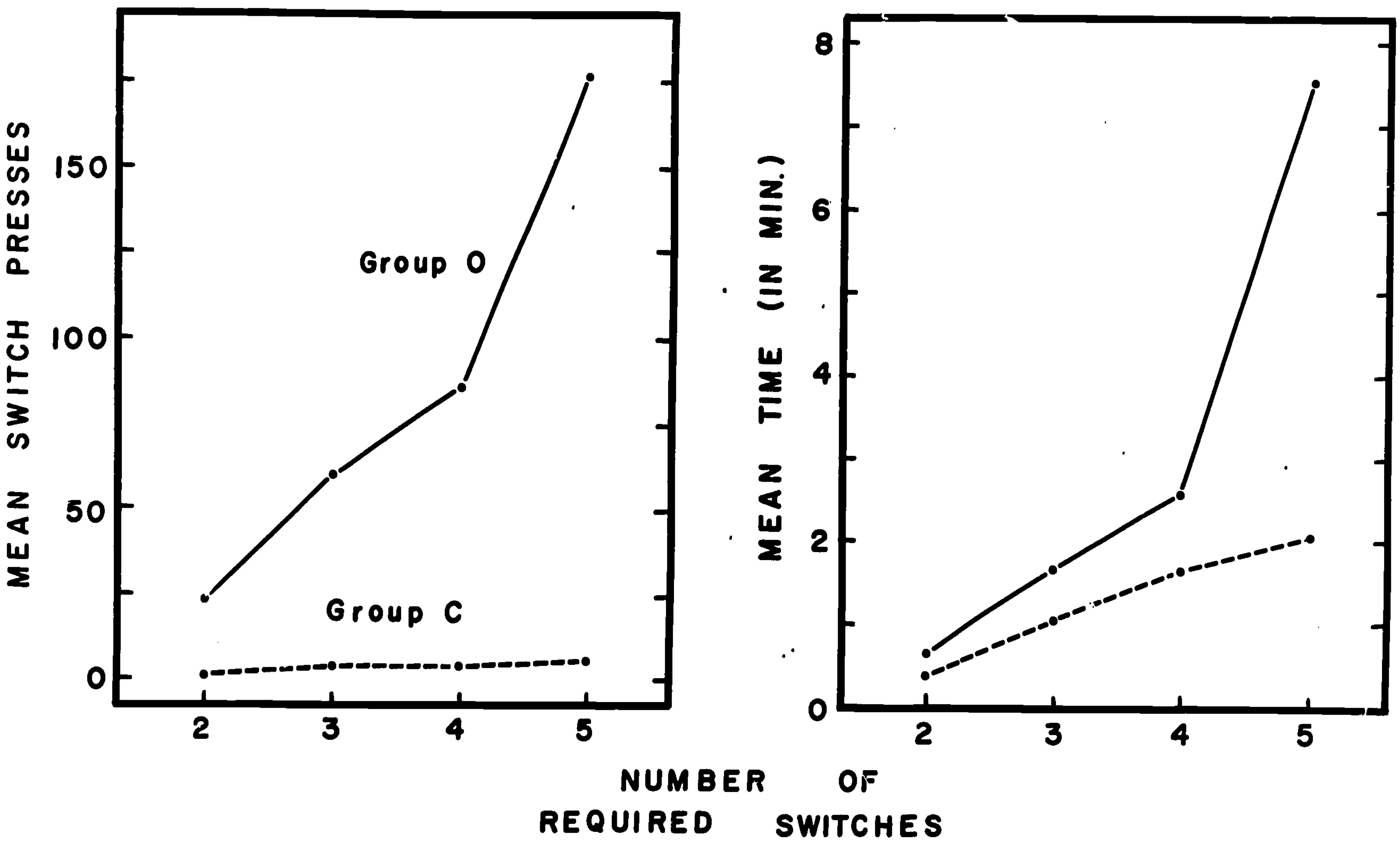

Fig. 3. Mean corrected switch presses and mean corrected time to criterion as a function of number of required switches and pretraining.

the ordinal position (columns) effect was significant, F (3,84) = 5.91, $p < .001$, indicating simply that Ss improved over problems. The pretraining by ordinal position interaction also was significant, F (3,84) = 5.02, $p < .01$, indicating that improvement was greater for Group O than for Group C.

An analysis of variance on the time to criterion measure produced results similar to the analysis of the switch-press measure. The pretraining effect was significant, F (1,24) = 7.34, $p < .025$. The number of required switches variable was significant, F (3,84) = 7.16, $p < .001$, for the main effect and F (1,84) = 19.34, $p < .001$, for the linear trend. The interaction of pretraining by number of required switches also reached significance, F (3,84) = 3.10, $p < .05$, although the divergence is clearly less than with the switch press measure. (See Figure 3) The ordinal position (columns) effect was significant, F (3,84) = 4.42, $p < .01$. However, the pretraining by ordinal position interaction was not significant, F (3,84) = 2.59, $.25 < p < .10$, reflecting the fact that both Groups O and C improved over trials.

The two halves of Figure 3, the switch press vs. time to criterion measures, show essentially the same effects of pretraining and number of required switches with one critical exception: The time measure, but not the switch press measure, shows that the performance of both the overt trial-and-error problem solvers (Group O) and the insightful or implicit problem solvers (Group C) deteriorated with longer response chains.

Trials and Mean Response Latencies

The trials measure (repetitions of the same problem) produced performance gradients and an analysis of variance table virtually identical to those of the switch press measure. The main effects of pretraining, number of required switches, and ordinal position were all significant at least at the .01 level; the pretraining by ordinal position and pretraining by required switches interactions were significant beyond the .05 and .001 levels, respectively.

Concerning mean response latencies, only the pretraining effect was significant, F (1,24) = 42.92, $p < .001$, indicating that the implicit problem solvers (Group C) responded more slowly than did Ss in Group O. No other main effect or interaction reached statistical significance.

In sum, Experiment II has shown that (1) as reflected in the time to criterion measures, both overt trial-and-error problem solving and implicit or insightful problem solving deteriorate when longer response chains are required for solution. (2) Also, two Ss in the untrained trial-and-error group (Group O) eventually learned the switch-light relationships well enough to solve one problem each in the errorless insightful fashion characteristic of Group C problem solvers.

IV
GENERAL DISCUSSION

In the present experiments, three seemingly important variables in human problem solving—the number of distracting response alternatives, the number of available response alternatives, and the length of the problem-solving response chain—were shown to influence performance in both an overt trial-and-error problem-solving task and in a covert "insightful" form of the same task. In regard to the contributions of these results to our understanding of problem solving as it may occur in the classroom, we are naturally limited by the artificiality of the laboratory procedures. Despite this limitation, however, there are some interesting generalizations which may shed light upon some aspects of classroom problem solving and, for that matter, problem solving in the real world.

First, regarding the effects of distracting response alternatives, it would seem that an understanding of this variable by teachers and curriculum specialists (a) would facilitate the construction of classroom problems and questions, (b) would provide insight into the prime source of difficulty students encounter in problem solving, and (c) would foster problem-solving skills to the extent that students are deliberately taught to "beware of distractors" or to "avoid jumping to conclusions."

Secondly, regarding the detrimental effects of increasing the number of available response alternatives, the effects of this variable can be greatly reduced simply by a systematic elimination of the various irrelevant alternatives. More efficient problem solvers were often seen systematically testing the relevance of each switch by working from right to left, row by row, rather than randomly testing and rejecting various switches. The implication for teaching, which has been noted elsewhere by Covington, Crutchfield, and Davies (1966) and by Torrance (1962), is that teaching the systematic elimination of solution alternatives is an effective means of improving problem-solving skills.

Finally, it is difficult to generalize from the finding that problems requiring a greater number of switches are more difficult, except to recognize this variable as an important dimension of many problems. It is likely that the ability to solve problems requiring longer response chains, or the ability to combine more problem units, would be closely related to students' developmental age.

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